

# Mass Bays Resource Inventory: Summary and findings from the review of plans and assessments

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## I. Introduction

The Massachusetts Bays Program (MBP) contracted with the Urban Harbors Institute (UHI) of the University of Massachusetts Boston to conduct a review of papers, presentations, reports, and other relevant material produced from 1996 (the last CCMP) to present, that might inform the MBP's update of their Comprehensive Conservation and Management Plan (CCMP). The review focused on five topics identified as priority topics by the MBP: water quality, invasive species, climate change/vulnerability, continuity of estuarine habitat, and estuarine habitat protection in the geographic region of the Mass Bays Program, particularly the 47 nearshore estuaries and embayments identified in the 2012 *MBP Estuary Delineation and Assessment* study prepared by Geosyntec.

UHI cataloged 539 resources, reviewed a portion—270—of them, and for each of these prepared brief descriptions of the purpose, data used, findings, and recommendations. This information is presented in a spreadsheet which accompanies this memo. Table 1 below summarizes the number of reports by topic, embayment, and region (note that reports could cover more than one topic and be in more than one region, so many are counted more than once).

This memo describes the methods used to identify and review the various resources, provides a summary of the resources and findings by topic (i.e., water quality, invasive species, climate change/vulnerability, continuity of estuarine habitat, and estuarine habitat protection), and offers observations and recommendations for the MBP as they update their CCMP.

Table 1. A summary of reviewed resources by topic and embayment shows broad representation across topics and embayments. Note: many reports covered more than one topic and more than one embayment.

Region	Embayment	Invasive Species	Climate Change	Habitat Continuity	Water Quality	Estuarine Habitat Protection
Upper North Shore	1	23	25	18	26	31
	2	25	27	24	27	35
	3	24	27	18	26	31
	4	22	25	24	29	30
	5	25	27	26	30	35
	6	21	24	14	24	27
	7	21	24	14	25	28
	8	20	24	14	24	27
	9	22	23	16	29	33
Salem Sound	10	20	24	12	24	26
	11	20	24	15	27	28
	12	21	24	14	24	27
	13	22	25	13	25	27
	14	20	24	11	23	25
	15	23	24	15	25	29
Boston Harbor	16	20	26	16	25	28
	17	19	24	12	22	26
	18	26	26	16	37	35
	19	20	26	17	34	31
	20	20	24	17	26	30
	21	22	26	19	27	33
	22	20	26	18	29	33
	23	24	32	22	45	43
South Shore	24	19	24	12	23	25
	25	19	25	14	26	27
	26	19	27	15	25	26
	27	19	27	16	28	28
	28	19	26	13	25	25
	29	20	26	14	26	28
	30	19	23	16	24	25
	31	21	22	16	25	26
	32	19	22	12	22	24
	33	19	22	14	22	24
Cape Cod	34	28	28	18	38	32
	35	25	28	16	38	32
	36	25	27	17	39	33
	37	22	27	16	35	30
	38	23	28	16	38	31
	39	23	27	16	39	31
	40	23	26	17	39	31
	41	22	27	15	40	32
	42	24	27	16	41	33
	43	22	28	17	39	30
	44	23	29	17	39	31
	45	23	30	17	38	32
	46	22	30	17	39	32
	47	22	30	17	39	32

## II. Methodology

The first step taken to develop the list of resources was to capture the online materials available from organizations and institutions with obvious connections to the topics identified by the MBP. Initial criteria for identifying resources included (1) a publication date between 1996 and the present (to reflect materials developed since the last CCMP); (2) relevance to the 5 topic areas mentioned previously; and (3) pertaining directly to at least one embayment as delineated by Geosyntec Consultants in their *Massachusetts Bays Program Estuary Delineation and Assessment* report. These online resources included the websites of the MBP Regional Coordinators, watershed organizations,

academic institutions, Sea Grants, regional planning agencies, and state agencies. The list was expanded with (1) contributions from a handful of the MBP Regional Coordinators and members of the MBP Management Committee, (2) references cited in each of the documents reviewed, and (3) documents located at the MBP's office.

While the list of resources provided to MBP is extensive, it is not comprehensive. Almost without exception, the review of a document with references led to the identification of other potentially relevant documents. Though the initial goal was to provide the MBP with complete information about all identified resources, it quickly became apparent that the list of relevant material was much more extensive than envisioned. In early October, the MBP and UHI agreed that UHI would continue to capture bibliographic information for all appropriate resources identified during the review of material, but that UHI would focus its review on a select group of documents, focusing on those reports and projects that (1) appeared to be of particular relevance, (2) had a publication date of 2000 or later, and/or (3) filled in spatial or topic-related gaps in terms of the coverage of reviewed documents. Thus, the final bibliography consists of both reviewed and un-reviewed resources.

The preliminary list of resources was entered into a spreadsheet shared on Google Docs. This allowed the UHI team to work simultaneously on the spreadsheet. Columns in the spreadsheet helped the team track who was working on a particular record, and captured bibliographic information such as title, author, and date. Another column captured information on the sponsor of the project, if any; and additional columns indicated a unique identification number for the resource and identified the topic(s) addressed by the resource<sup>1</sup>. The spreadsheet was also used to record information about the purpose of the material, the findings presented, the scope and source(s) of data, and the nature of the recommendations (e.g., topics covered by the recommendations and any particularly relevant recommendations or observations about the recommendations), if any. Lastly, the spreadsheet was also used to track the overlap between the resources and the embayments within the MBP, as described by Geosyntec Consultants in their *Massachusetts Bays Program Estuary Delineation and Assessment* report.

Electronic copies of all reviewed resources have been compiled (they are noted in the database) and are being provided to the MBP as part of the deliverable for this project.

One type of document that is represented in the bibliography, but is not comprehensively captured because of sheer numbers, is town plans – more specifically, Open Space and Recreation Plans, Harbor Plans, Comprehensive Plans, and Multi-hazard Mitigation Plans. These are common among the communities and very often, though not always, include data and assessments of habitat, environmental quality, and climate change topics. It would be very time consuming to compile and review all of these plans, but it may be worthwhile for the MBP to review these types of plans for communities in which they intend to undertake specific projects.

The following sections generally describe the resources reviewed in each of the five themes. Where appropriate, titles for specific reports are identified both by title and by the corresponding identification number in the spreadsheet for easy reference. While recommendations are identified within each topic area, they are analyzed and discussed collectively in the final section of the report.

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<sup>1</sup> Many of the documents in this category addressed more than one topic of interest to the MBP. All relevant topics have been indicated in the spreadsheet of resources.

### III. Water Quality

The water quality category refers to studies that discuss the chemical, physical, or biological characteristics of water. These characteristics are often evaluated for their impact on ecosystem or human health. Typical water quality parameters include nutrients, bacteria, and harmful chemicals. This topic consists of a broad range of studies, including studies of individual parameters in individual embayments, to wide-ranging synthesis papers that utilize large datasets with multiple parameters to examine water quality for all Massachusetts coastal waters. While some reports focused solely on water quality, the topic was also commonly a chapter or a theme in other reports focusing more broadly on topics such as habitat restoration, where water quality was one of many different components.

Water quality is of paramount concern in Massachusetts coastal embayments, as evidenced by the large number of documents examined. For this literature review, 145 documents with a water quality component were reviewed. Boston Harbor and its related embayments had the most reviewed reports (69), while four embayments – Marblehead Harbor, Belle Isle Creek/Winthrop Bay, Ellisville Harbor, and Great Herring Pond/Bournedale - had only 27 documents. Many documents pertaining to water quality on Cape Cod applied to all of the Cape Cod embayments. Twenty-two of the reports applied to or could potentially apply to the whole MBP region.

Many of the water quality documents examined were the result of scientific sampling of various water quality parameters. These studies present the data but do not contain recommendations for future planning. However, some themes common to multiple documents include:

- Water quality is directly tied to estuarine habitat protection and continuity
- Sea level rise could affect drinking water quality and quantity, particularly on Cape Cod
- Wastewater and stormwater management have direct impacts on water quality
- Open space acquisition/preservation is viewed as a valuable tool for protecting water quality

Some documents offer project-specific recommendations, including improvements to data collection methods. Many comprehensive town plans have water quality recommendations which might be extended to other embayments. Others provide advice about protecting water quality during restoration work or while operating water-dependent businesses such as marinas.

The MBP might be most useful organizing the various stakeholders, funders, and partners to tackle areas where data is lacking – especially data that can be used to identify illicit sewer hook-ups (see *Boston Harbor South Watersheds 2004 Assessment Report* (17)).

Many of the reports end with a recommendation to conduct additional research within the embayment. For some smaller studies, additional data is needed to extrapolate results to larger areas. The MBP might consider working with its network of university and volunteer organization partners to increase volunteer monitoring capacity.

Reports also indicated a need for better education pertaining to water quality and quantity issues (e.g., *Controlling Combined Sewer Overflows in Chelsea, MA: Analysis of Green vs. Gray Infrastructure* (131); *Ipswich River Watershed Action Plan* (39)). The MBP might specifically look to educate communities about the advantages of green infrastructure for the treatment of stormwater runoff; BMPs to prevent stormwater pollution, maintenance and repair guidelines for stormwater management systems, and steps towns, companies, and homeowners can take to reduce water demand (see page 60 of *Status of and Potential Impacts on Water Budget for the Weir River Watershed* (44) for good examples of ways to promote reduced water demand).

While many reports identified impaired waterbodies, the water flow issues identified on the Ipswich River (*Ipswich River Watershed Action Plan* (39)) seem to be one area of critical importance. The MBP

may have expertise to contribute or may be able to help leverage funding for projects to remove dams and restore water flows to restore and improve fish migration.

Some water quality reports of note include:

- *Controlling Combined Sewer Overflows in Chelsea, MA: Analysis of Green vs. Gray Infrastructure* (131)
- *Eutrophication and Aquatic Plant Management in Massachusetts: Final Generic Environmental Impact Report* (86)
- *Ipswich River Watershed Action Plan* (39)
- *National Estuarine Eutrophication Assessment: Effects of Nutrient Enrichment in the Nation's Estuaries* (88)
- *Parker River Watershed: Year 3 Watershed Assessment Report* (231)
- *Status of and Potential Impacts on Water Budget for the Weir River Watershed* (44)
- *Total Maximum Daily Loads of Bacteria for Little Harbor* (248)
- *Boston Harbor South Watersheds 2004 Assessment Report* (17)

#### **IV. Estuarine Habitat Protection**

“Estuarine habitat protection” is a broad topic, encompassing many different natural resources and the interaction between resources and stressors, all as part of “habitat”. Furthermore, the topic includes the ability to protect, manage, and restore those resources. Given the breadth of this topic area, the focus was to capture studies and reports addressing habitat protection *and restoration* in the estuarine environment, including protection and restoration methodologies, stressor identification and reduction, and resource management.

The wide range of natural resources considered “habitat”, and the multiple ways that protection, restoration, and management can be conducted, led to the inclusion of many different types of documents in this category, including town comprehensive plans, habitat protection methodology studies, natural resource inventories, harbor plans, and beach management plans. These resources addressed many different elements of estuarine habitat as well as their stressors (e.g., marshes, rivers, sand dunes, beaches, eelgrass beds, climate change, water quality, etc.). Most of the documents identified in this category also touch upon the other topics of interest to the MBP because of the connection between habitat protection and planning for climate change, protecting against invasive species, improving water quality, and promoting habitat connectivity. The scale of these documents ranged from small isolated sites to much larger areas such as the Gulf of Maine.

The UHI team reviewed 118 resources in the estuarine habitat protection category. This topic is well represented across all embayments in the MBP region. Boston Harbor had the largest number of reviewed reports (43) while Ellisville Harbor and Great Herring Pond/Bournedale had the fewest (24 each). Twenty-two of the reports applied to or could potentially<sup>2</sup> apply to the whole MBP region.

The examination of resources uncovered through this project clearly shows that different types of estuarine habitat protection efforts have taken place or been studied or planned, at many different scales within the MBP planning area. Many of the documents reviewed in this section are plans intended to be valid for several years; thus, some of the recommendations are ongoing.

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<sup>2</sup> Some resources provided guidance on topics such as shellfish bed and dune restoration methods which will only apply to those embayments in need of dune restoration or with suitable shellfish restoration sites. Without knowledge of each embayment’s specific needs and opportunities, such resources were identified as being applicable to all embayments.

While much is being done to ensure and advance estuarine habitat protection, some key needs and perspectives did emerge, including that climate change is anticipated to have significant impacts on estuarine habitats, that water quality and quantity play a major role in estuarine habitat protection, and that collaboration on estuarine habitat protection efforts is useful. The MBP might consider becoming involved in better addressing these needs. More specifically:

- Climate change is anticipated to have significant impacts on estuarine habitats and is a part of, if not a major focus of, many estuarine habitat protection, restoration, and management documents. Issues such as coastal flooding, loss of shoreline, and invasive species appear in many of the reviewed estuarine habitat documents. Monitoring for changes relative to sea level rise are time and resource intensive, yet the significance of monitoring was clearly stated in several documents. The MBP might help connect university students and faculty with climate change monitoring needs to help increase monitoring capacity and assist with vulnerability analyses (see *Boston Harbor Islands National Park Areas in 2016: Strategic Plan* (308)).
- Habitat connectivity issues, including fragmentation of coastal habitat due to development, and loss of spawning habitat due to low water levels, were identified in several documents pertaining to estuarine habitat protection. In those documents, recommendations for water level monitoring and public education were abundant. Monitoring and public education were also recommended in several documents addressing water quality issues. Given the MBP's connectedness throughout the program area, the MBP is in a position to help develop and disseminate educational material addressing these topics (e.g., sharing case studies, providing training programs or education materials about BMPs, clearly identifying and publicizing the threats to estuarine habitats). Audiences could include the general public, industry leaders, and decisions makers at the municipal, regional, and state levels (see *Charting the Course* (267)). The seven principles of ocean literacy may serve as a useful guide for some of the public outreach materials.
- Collaboration was identified in several reports as being important to advancing estuarine habitat protection and restoration (e.g., *Waves of Change: The MA Ocean Management Task Force Report and Recommendations* (8); *Cape Cod Comprehensive Regional Wastewater Management Strategy Development Project* (65); *Charting the Course* (267); *Inventory of Intertidal Habitats: Boston Harbor Islands, a national park area* (especially pertaining to invasive species)(292)). Some habitat restoration efforts are necessarily focused on specific sites, but several resources make a point that, when possible, habitat restoration would benefit from regional cooperation and collaboration – especially for water quality and quantity issues, invasive species monitoring and management, and habitat connectivity issues. As such, one clear opportunity for the MBP is to serve as a convener of parties with similar estuarine habitat protection interests and needs. For example, many groups are or have been working on similar issues such as understanding the impacts of sea level rise on marsh habitats (including National Park Service, MA CZM, MIT Sea Grant), working to restore eelgrass beds (including Massport, MA DMF, the Town of Provincetown, EPA, MA CZM), and improving diadromous fish habitat (including MA DMF and watershed associations). The MBP might consider hosting topic-specific meetings or conferences to bring these groups together so that they can learn from each other and identify opportunities for collaboration and cooperation (see *Charting the Course* (267); *Inventory of Intertidal Habitats: Boston Harbor Islands, a national park area* (292)).
- Several reports refer to the need for more economic valuation of natural resources, along with the need to better understand the economic incentives, disincentives, and tools pertaining to habitat protection and restoration (e.g., *Parker-Ipswich-Essex Rivers Restoration: Recommended*

*Actions (1); Successful Eelgrass (Zostera marina) Restoration in a Formerly Eutrophic Estuary (Boston Harbor) Supports the Use of a Multifaceted Watershed Approach to Mitigating Eelgrass Loss (24); Massachusetts Clean Marina Guide (60)*). Some specific topics that the MBP might wish to explore are the economic valuation of eelgrass (which does not come from a reviewed report, but was mentioned as UHI researched the conservation mooring report); economic drivers for water use and water conservation (see *Parker-Ipswich-Essex Rivers Restoration: Recommended Actions (1)*); and economic tools (e.g., fees, taxes, tax incentives, grants and matches, mitigation funds, stormwater utilities) for conducting habitat protection and restoration (see *Parker-Ipswich-Essex Rivers Restoration: Recommended Actions (1); Charting the Course (267); Massachusetts Clean Marina Guide (60)*).

- Among the many different types of habitat addressed in these reports, eelgrass protection and restoration seems to be attracting great interest (see *Eelgrass (Zostera marina) Restoration and Monitoring Technical Guidelines (359); A Study of Eelgrass Beds in Boston Harbor and Northern Massachusetts Bay (368); Determining eelgrass habitat suitability in the Annisquam River, Gloucester Harbor (369); Application of the Preliminary Transplant Suitability Index (PTSI) Model for Eelgrass, Zostera marina, in Annisquam River-Gloucester Harbor, Massachusetts, A study of the relationship between water quality, coastal geomorphology and eelgrass (Zostera marina L.) meadows in Massachusetts Bay (370); Mapping Eelgrass in Massachusetts, 1993-2003 (280); Adaptive management for impacts to eelgrass habitat in Gloucester Harbor (388); Restoring eelgrass, Zostera marina L., habitat using a new transplanting technique: The horizontal rhizome method (282); Quantifying the effects of green crab damage to eelgrass transplants (266); Successful Eelgrass (Zostera marina) Restoration in a Formerly Eutrophic Estuary (Boston Harbor) Supports the Use of a Multifaceted Watershed Approach to Mitigating Eelgrass Loss (24)*). Though much has been done to understand eelgrass protection and restoration, many questions remain. The MBP should continue its work with this habitat, assisting with research projects and disseminating the findings in order to guide others working to protect and restore this fragile habitat. Of particular interest are questions about site selection strategies, transplant methods, and stressors that impact the success of restoration projects.
- Given its regional nature and access to a wealth of data resources the MBP may consider implementing a recommendation similar to one in *Waves of Change: The MA Ocean Management Task Force Report and Recommendations (8)*. This report (on p. 52) suggests that a team “fully leverage existing historic data to contribute to our understanding of estuarine and marine ecosystems, thereby leading to improved resource management.” This analysis of trends in data could assist with setting specific goals/targets for the MBP, and can contribute to the establishment of baselines, the assessment of cumulative impacts, the estimation of minimally-disturbed population levels, and the identification of new issues or trends.

Additionally, though the MBP is looking to focus more on specific embayments and these five priority topic areas, several reports noted the need to address habitat issues on a regional scale (though “region” varied from watershed, to multi-town, to multi-state regions), and the importance of managing habitat as part of a larger ecosystem.

## V. Habitat Connectivity

“Habitat connectivity”<sup>3</sup> is the ability of the aquatic and terrestrial habitat to facilitate the movement of animal and plant species, as well as natural resources such as water and nutrients, across a geographical range. Such connectivity allows for species migration, whether as part of a natural life cycle or as a shift to adjacent areas in response to a local loss of habitat. Fragmentation of habitat threatens biological diversity because it disrupts biological processes and ecological flows by reducing the total habitat area, separating aquatic and terrestrial habitats from each other, and disrupting influences from surrounding habitat. As a result, maintaining habitat connectivity is essential for a thriving ecosystem.

Habitat connectivity can be studied through examination of numerous sub-topics. The UHI team focused primarily on studies and reports that address connectivity of the aquatic environment, with less focus on habitat corridors in the terrestrial environment or the connections between the aquatic and terrestrial environment.

This category consists of many different types of documents including watershed action plans, harbor plans, town comprehensive plans, original research and data collection studies, USGS Scientific Reports, and conference abstracts. These resources address many different issues of habitat connectivity, such as stream water volume and flow frequency, dam removal, fish ladders and other fish passages, water conservation, current status of selected fish species, and dredging.

Many of the documents identified in this category also address other topics because of the inherent connection between habitat connectivity and habitat protection, water quality concerns, the introduction and spread of invasive species, and planning for climate change. The scale of these documents ranged from isolated sites on one river, to state-wide sampling in both coastal and inland waters, to much larger areas such as the Gulf of Maine region.

The UHI team reviewed 78 resources in the habitat connectivity category. This topic is generally well represented across all embayments in the MBP region. Plum Island Sound had the largest number of reviewed reports (32), while Marblehead Harbor had the fewest (11). When evaluating the number of documents on a regional scale, the Cape Cod Region (215) and the Upper North Shore Region (169) were the most well represented, while the Salem Sound region (80) was the least represented. Ten of the reports applied to or could potentially<sup>4</sup> apply to the whole MBP region. Often these reports were applicable to the whole MBP region not because site-specific sampling had occurred in each of the embayments, but because the report was a broader scale planning document for the entire state or Gulf of Maine. From the reviewed documents, habitat connectivity has been studied via various topics at different scales throughout the MBP planning area. Due to a lack of comprehensive local knowledge, however, it is uncertain whether all critical topics in a specific embayment have been addressed.

Through this survey of resources, key priorities emerged that can help to guide future research and action in the area of habitat connectivity. Priorities include site-specific recommendations, the need for additional data, and the interconnected nature of the MBP topic areas. More specifically:

- Many of the most valuable recommendations proposed in the documents were in the form of site-specific recommendations. These recommendations relate to a variety of topics, including:

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<sup>3</sup> Commonwealth of Massachusetts. 2006. Comprehensive Wildlife Conservation Strategy. Retrieved from <http://www.mass.gov/eea/docs/dfg/dfw/habitat/cwcs/mass-cwcs-final.pdf>

<sup>4</sup> Some resources provided guidance on topics such as shellfish bed and dune restoration methods which will only apply to those embayments in need of dune restoration or with suitable shellfish restoration sites. Without knowledge of each embayment’s specific needs and opportunities, such resources were identified as being applicable to all embayments.

- New fishway locations, structural and design changes to fishways as well as improved maintenance (see *North and South Rivers Stream Prioritization Project* (405), *Final Watershed Plan and Area-wide Environmental Impact Statement for the Cape Cod Water Resources Restoration Project* (33), and *A survey of anadromous fish passage in coastal Massachusetts: Part 2. Cape Cod and the Islands* (400), *Part 3. South Coastal* (401), and *Part 4. Boston and North Coastal* (402));
- Improvement or creation of water management plans (see *Balancing the Water Budget in Ipswich, MA - Model Financing Mechanisms for Integrated Water Resources Management* (396), and *Newbury Estuarine Management Plan* (2));
- Restoration sites for salt marshes and mud flats (see *Final Watershed Plan and Area-wide Environmental Impact Statement for the Cape Cod Water Resources Restoration Project* (33), and *The Economic Impacts of Ecological Restoration in Massachusetts* (270)).

Recommendations in these general topics can be found in many locations; however, given the unique conditions and priorities of each location, these recommendations cannot be extrapolated uniformly to a wider geographic range without scientific research and consideration. At the same time, lessons can be learned in locations where these recommendations are implemented for potential use elsewhere.

- Documents often indicated a need for more data about specific issues related to habitat connectivity. These issues include:
  - Monitoring programs regarding the population status of specific fish species and causes of habitat degradation, which is necessary for resource management and to identify restoration strategies (see *Rainbow smelt (*Osmerus mordax*) spawning habitat on the Gulf of Maine coast of Massachusetts* (274));

Developing response models based on life history and behavioral and ecological requirements may provide a better understanding of fish assemblage responses to urbanization than approaches using total species richness (see *Fish assemblage responses to urban intensity gradients in contrasting metropolitan areas—Birmingham, Alabama, and Boston, Massachusetts* (415));

- Using a variety of study designs, including multilevel hierarchical models, that are conducted at a range of geographic scales, to understand the relationships between invertebrate responses and watershed-scale and regional-scale variables (see *Urban streams across the USA – lessons learned from studies in 9 metropolitan areas* (411)).
- Habitat connectivity is inextricably linked with other MBP topic areas, in particular water quality and estuarine habitat protection. Prevention of fragmentation of habitat areas, sufficient water levels, and minimal water contaminants are fundamental pieces of a healthy ecosystem. Habitat connectivity should be studied in conjunction with these topics as much as possible. Water quality monitoring and public education about habitat protection are important aspects of such research (see *Boston Harbor Islands - A National Park Area, Massachusetts Water Resources Scoping Report* (31), *Parker-Ipswich-Essex Rivers Restoration: Recommended Actions* (1), and *Mystic River Watershed Assessment and Action Plan* (25)).

An effective use of MBP expertise, regional knowledge, and local connections could be to serve as a leader in the coordination of data and outreach efforts regarding habitat connectivity. In particular, MBP could compile a priority list of additional data that would provide valuable guidance for future research efforts. In addition, depending on the scale or specificity of data required, MBP could coordinate portions of this data collection, as well as engage in public education about these issues.

## VI. Invasive Species

Invasive species are plant and animals species that are not native to a geographic area, but that after they are introduced to the area, they are able to become established and thrive. Invasive species often proliferate and outcompete native plant and animal species to such a degree that these native species are threatened. Invasive species may damage native species through a decrease in local population size, increased prevalence of disease, and loss of habitat and space, among other threats. In some locations, an invasive species may completely eradicate a particular native species. Invasive species are a significant threat not only to local biodiversity, but also to local physical infrastructure and ecosystem services. Invasive species are known by a variety of names, including non-native species, nuisance species, non-indigenous species, exotic species, or marine or terrestrial invaders. These species may be introduced to a new geographic area either by intentional or accidental means. The UHI team focused on any applicable invasive species, within a variety of geographic scales.

This category consists of many different types of documents including watershed action plans, harbor plans, beach management plans, town comprehensive plans, original research and data collection studies, and conference abstracts. These resources address a variety of invasive species, some of which are well-established in Massachusetts, while others have only recently begun to encroach into Massachusetts waters.

Many of the documents identified in this category also address other topics because of the inherent connection between the spread of invasive species, and the effects of climate change, habitat connectivity and habitat protection, and water quality concerns. The scale of these documents ranged from isolated sites in one coastal area, to state-wide sampling in both coastal and inland waters, to much larger areas such as the Gulf of Maine region. This variety in geographic range is appropriate because of the potential danger posed by these species, and the ability of some invasive species to expand rapidly. The range must encompass those invasive that have spread widely across the region, as well as those in isolated locations, with the potential to expand widely and rapidly. Mapping the locations of invasive species over time can indicate whether these species are relatively stable in one area or are actively expanding into new areas.

The UHI team reviewed 50 resources in the invasive species category. The topic is generally well represented across all embayments in the MBP region. Boston Harbor had the largest number of reviewed reports (28), as well as Chelsea Creek/Mystic River/Charles River (26), while several areas (Belle Isle Creek/Winthrop Bay; the area on the South Shore from Little Harbor to Green Harbor, as well as Ellisville Harbor) tied for the fewest (19). When evaluating the number of documents on a regional scale, the Cape Cod Region (328) and the Upper North Shore Region (204) were the most well represented, while the Salem Sound region (127) was the least represented. The area around the northern end of the Cape Cod Canal is a frequent sampling site, although the sampling locations often were not sufficiently specific to be able to identify whether sampling was conducted in an MBP embayment or not .

Nineteen of the reports applied to or could potentially<sup>5</sup> apply to the whole MBP region. Often these reports were applicable to the whole MBP region not because site-specific sampling had occurred in each of the embayments, but because the report was a broader scale planning document for the entire state or Gulf of Maine, due to the ability of an invasive species to proliferate across a broad area. From

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<sup>5</sup> Some resources provided guidance on topics such as shellfish bed and dune restoration methods which will only apply to those embayments in need of dune restoration or with suitable shellfish restoration sites. Without knowledge of each embayment's specific needs and opportunities, such resources were identified as being applicable to all embayments.

the reviewed documents, invasive species have been studied at different scales throughout the MBP planning area.

Through this survey of resources, key priorities emerged that can help to guide future research and action in the area of invasive species. Priorities include the need for more research on specific species, the importance of long-term research, and the value of educating the public about invasive species.

More specifically:

- Additional research is needed for specific species to determine distribution and further movement. In particular, researchers note the importance of further study on the Asian red seaweed *Grateloupia turuturu* (Rhodophyta) which recently has migrated north from Narragansett Bay as far as Boston and has the potential to cause significant ecosystem and economic losses (see *The Asian red seaweed Grateloupia turuturu (Rhodophyta) invades the Gulf of Maine* (451)). Also, further hydrologic studies and management strategies are needed for *Phragmites australis* in Massachusetts waters (see *Investigating Causes of Phragmites Australis Colonization in Great Marsh, Parker River National Wildlife Refuge* (447); and *Evaluation and Management in the Upper Great Marsh: Emergent Phragmites australis* (293)).
- Significant data gaps exist regarding the impacts, particularly the economic impacts of marine invasive species in the Gulf of Maine. Fisheries and aquaculture industries are known to have suffered losses; however, these losses have not been quantified. Further empirical studies are needed to address this lack of data on the specific economic impacts of marine invasive species (see *Marine Invasive Species - State of the Gulf of Maine Report* (432)).
- Invasive species pose a significant threat to the ecology and economy of the areas they colonize. Due to their potential mobility, invasive species are able to expand their range and colonize new areas, often at a rapid pace. Long-term studies are fundamental to understanding the dynamics of invasive species, and the factors and trends affecting their progress or stagnation. As more data is gathered over time, government officials, policymakers, and the public will have better information for improved decision-making. For example, the series of rapid assessment surveys conduct in the Northeast over the past decade is an invaluable resource for assessing the status and movement of invasive species (see *Marine Invaders of the Northeast: Rapid assessment survey of native and non-native marine species of floating dock communities, August 2003* (444); and *Report on the 2010 Rapid Assessment Survey of Marine Species at New England Floating Docks and Rocky Shores* (437)).
- Education of the public about invasive species is fundamental to successful management. Teaching citizens about how to identify species or methods of removal, can provide significant assistance to government and create a more effective outcome (see *Monitoring Marine Invasive Species: Guidance and Protocols for Volunteer Monitoring Groups* (436));

The MBP is already a leader in invasive species issues in Massachusetts. MBP, together with the Massachusetts Office of Coastal Zone Management (CZM) developed the *Massachusetts Aquatic Invasive Species Management Plan* (434) in 2002. The MBP is a member of the Massachusetts AIS Working Group, which implements the Plan. In addition to maintaining this important role, the MBP could continue to support and promote long-term studies, such as the series of rapid assessment surveys in the Northeast, to ensure that decision-makers have access to the full-range of information and trends on invasive species. Given the lack of information on the economic impacts of marine invasive species, the MBP could initiate and support empirical studies on this topic. In addition, the MBP could continue to support public education about invasive species so that citizens can help fight against these local threats.

## VII. Climate Change and Sea Level Rise

“Climate change is the greatest environmental challenge of this generation, with potentially profound effects on the economy, public health, water resources, infrastructure, coastal resources, energy demand, natural features, and recreation” (Massachusetts Climate Change Adaptation Report, 2011). It is anticipated that climate change will exacerbate a number of threats faced by the natural and built environments of the coastal area. Accelerated sea level rise and an increase in the frequency and intensity of storms, both attributed to climate change, can be expected to increase beach and shoreline erosion, damage homes, businesses and infrastructure, threaten human lives and well-being, lead to loss of habitat, and cause pollution of coastal waters from increased upland runoff. Salt marshes, beaches and floodplains which provide important ecosystem services such as habitat, nutrient uptake, recreation, and upland flood protection, are particularly susceptible to sea level rise. Climate change is also affecting ocean temperatures, currents, and chemistry resulting in changes to biodiversity, and the health and distribution of species, all of which have the potential to impact local economies dependent on coastal and ocean resources.

There has been and continues to be much effort at the international and national scale to document and project global temperature changes and associated impacts (*Global Sea Level Rise Scenarios for the US National Climate Assessment Report*, 539). At a regional and local scale, e.g., Mass Bays, studies, reports, and plans focus on the implications of these models’ predictions.

Seventy-two documents were reviewed out of 101 compiled for this topic area. The number of documents involving the geographic areas of the estuaries was quite consistent ranging from 24 to 28. By region, the number of documents ranged from a high of 393 applicable to the Cape Cod region, to the South Shore region with 244, the North Shore region with 234, the Boston region with 218, and Salem Sound with 145. Almost all of the documents are dated from the early 2000s to the present reflecting the relatively recent recognition of and attention to the importance of this topic.

Researchers have prepared assessments of climate change and its anticipated impacts on the ocean and coastal ecosystems and their components (e.g., salt marshes) at a range of scales from the regional (Gulf of Maine) down to the sub-local (individual estuaries). In general, these adaptation studies document the existing conditions, values and vulnerabilities of natural resources, fish and wildlife habitat (e.g., *Climate Change and Massachusetts Fish and Wildlife, Vols. 1-3*, 265, 268, 300) infrastructure such as publicly-owned coastal protection structures (*Massachusetts Coastal Infrastructure Inventory and Assessment Project*, 299) and services (e.g., aquifers), and private property (*Mapping and Analysis of Privately-Owned Coastal Structures*, 476). Other research studies document the extent of future flooding and estimate the change in recurrence intervals of storm surges. Social scientists have worked with community residents to better understand factors that produce human vulnerability, the acceptability of alternative responses to SLR, and the different abilities of people to cope with hazards.

The Commonwealth and a number of coastal municipalities have convened inter-agency and multi-disciplinary committees to prepare reports on the nature of the impacts that can be anticipated, assessments of vulnerability, and policies, strategies and recommendations, both short- and long-term, for mitigating climate change and adapting to its impacts, including most significantly, sea level rise. The *Massachusetts Climate Change Adaptation Report* (474) is a good overall presentation of the predicted changes, vulnerabilities and climate change adaptation strategies. Much work has been done in the Parker-Ipswich, Essex Rivers, and Great Marsh area on predicted wetlands loss (*Effects of Storm Surge and SLR*, 471). The *Parker-Ipswich-Essex Rivers Restoration* report, (1) offers a comprehensive set of recommendations including research and monitoring needs. On the South Shore, *Sea Level Rise Study, Duxbury, Marshfield, Scituate, MA* (463) is an excellent example of vulnerability assessment, particularly for public awareness purposes. The potential impact of sea level rise on drinking water aquifers is

explored in *Simulated Interaction between Freshwater and Saltwater* (106, 107). *Salt Marshes, Storm Surge, and Sea Level Rise: A Web-based Mapping Tool to Support Land Use Planning* (296) is a practical example of assessing the vulnerability of salt marsh to SLR. MCZM has produced or sponsored considerable information on areas of potential inundation (tidal and storm flooding) under several scenarios and strategies and measures to protect buildings and resources. As a baseline for understanding the vulnerability of the shoreline, the historical rates and trends of shoreline change along the Massachusetts over the 165 year period from 1844 through 2009 have been documented in *Massachusetts Shoreline Change Mapping and Analysis* (485).

Many municipalities or regions have vulnerability assessments and some level of response planning. The City of Boston and several other communities have produced a sequence of studies and reports throughout the past decade on the impacts of climate change and mitigation and adaptation strategies. A 2005 report provides vulnerability and risk assessments and mapping for the Salem Sound towns (*Climate Change Ready or Not*, 500). The City of Boston is probably the most advanced in its assessments and planning with its *Climate Ready Boston* (510) and *Building Resilience in Boston: Best Practices for Climate Change Adaptation and Resilience for Existing Buildings* (511). These can serve as good references for other municipalities undertaking these tasks. *Preparing for the Rising Tide* by The Boston Harbor Association is an oft-referenced report (462) presenting several case study sites. Most cities and towns have adopted multi-hazard mitigation plans. These plans fulfill the federal regulations for the Federal Emergency Management Agency's (FEMA) Mitigation Planning, under the Code of Federal Regulations (CFR) Title 44 Part 201. All cities and towns are required to adopt local multiple-hazard mitigation plan in order to remain eligible for the Federal Emergency Management Agency (FEMA) Hazard Mitigation Grant funds (available after a disaster is declared) and to be eligible for other federal hazard mitigation funds. Most communities have updates of the original plans that were prepared on or around 2004. The plans identify new and on-going hazards in the community, assess the mitigation strategies of the original plan, and recommend new strategies where necessary. Generally, the eight natural hazards covered by these plans are flood, shoreline change, wildfire, wind, snow and ice accumulation, drought, tornado, and earthquake. In addition, many of these plans make reference to sea-level rise and increased precipitation, two projected local impacts of climate change, as a factor that threatens to increase the risks and vulnerabilities associated with flooding and shoreline change. Adaptation strategies were discussed for their potential to mitigate these impacts.

The regional planning agencies are active in preparing regional multi-hazard mitigation plans and assisting their communities with their plans. The Barnstable County plan prepared by the Cape Cod Commission includes five local plans for: Provincetown, Eastham, Dennis, Chatham, and Truro. The other eight towns: Barnstable, Brewster, Bourne, Harwich, Mashpee, Orleans, Sandwich, and Wellfleet are in preparation. MAPC is in the process of developing a regional climate change adaptation strategy encompassing a set of policies and measures to reduce vulnerabilities and impacts associated with climate change. MAPC is also actively assisting a number of communities in its service area with these plans.

This topic is receiving a great deal of attention from all levels of government, academics and practitioners. Vulnerability assessments, especially on the built environment (public and private) and human life, and strategies for adaptation to protect property and life are being developed and adopted. Impacts on habitat and living resources have received relatively less attention. The Mass Bays program can make a contribution in this area.

## VIII. Summary and Recommendations

This report clearly shows the vast extent to which the topics of interest to the MBP have been addressed in the various embayments since 1996. While the large number of documents made this project a challenge in terms of being able to provide a comprehensive review of all resources, it is reassuring to know that so many are engaged in work relevant to the MBP's priorities, and that the MBP is neither starting from scratch nor operating in a vacuum. Instead, the MBP has a wealth of data and partners to draw from as it works to update and implement its next CCMP. Additionally, the work done to date on these topics demonstrates a need for the MBP's involvement in and support of ongoing monitoring (generally in water quality, water flow, invasive species identification, climate change monitoring), funding of projects, public education, and capacity building. Specific recommendations for the MBP as it updates its CCMP include:

1. Assist directly and indirectly with monitoring activities relative to climate change, invasive species, habitat fragmentation, natural resource protection, and water quality and quantity
  - a. Support monitoring through regional partners
  - b. Consider funding monitoring activities in addition to the research and planning grants
  - c. Work with the existing MBP network to identify new volunteers (e.g., college students and faculty) to fill gaps in monitoring efforts
2. Develop and disseminate public education/outreach materials
  - a. Work locally and regionally to increase public understanding of issues including the impacts of climate change, especially on natural resources; human impacts on water quality and quantity; and industry best management practices
3. Promote regional collaboration and cooperation
  - a. Conduct topic-specific workshops and conferences to improve communication, collaboration, and cooperation among people/groups working on similar issues
  - b. Develop methods for the sharing of resources (e.g., equipment, volunteers, data)
  - c. Participate in regional planning activities (e.g., Gulf of Maine Council; Metropolitan Area Planning Council, Watershed Associations, Cape Cod Commission)
4. Improve the current understanding of the economic value of coastal resources, along with economic incentives, disincentives, and tools pertaining to habitat protection and restoration
  - a. Conduct an analysis of the economic value of eelgrass
  - b. Conduct an analysis of the economic impact of marine invasive species
  - c. Better understand the economic drivers for water use and water conservation
  - d. Share information about economic tools (e.g., fees, taxes, tax incentives, grants and matches, mitigation funds, stormwater utilities) for conducting habitat protection and restoration activities
5. Continue to engage in eelgrass research and restoration projects
  - a. Conduct and fund projects that advance the understanding of eelgrass restoration success. Of particular interest are questions about site selection strategies, transplant methods, and stressors that impact the success of restoration projects

6. Gather and conduct an analysis of existing data to establish trends and baselines to guide management
  - a. Use existing data to establish baselines for impacts from climate change, including coastal resource migration related to sea level rise
  - b. Use existing data to establish benchmarks/goals for the CCMP

Resources identified for this project received support from a variety of different types of funders ranging from state and federal entities to private foundations, municipalities, regional planning agencies, land owners, and NGOs. Some of the funders are already likely familiar to the MBP and may be prospective funders and partners, while others may be new to the MBP. A list of potential funders and partners is presented below:

Potential new partners for Management Committee:

- National Oceanic and Atmospheric Administration
- National Park Service
- MA Areas of Critical Environmental Concern Program
- MA Natural Heritage and Endangered Species Program
- Massport
- Cape Cod Commission
- Municipality representatives within MBP region (Conservation Commissioners, Harbormasters)
- Cape Cod Cooperative Extension
- Massachusetts Audubon Society

Potential new project partners – these groups might be interested in partnering (not funding) with the MBP on research and/or restoration activities:

- National Oceanic and Atmospheric Administration
- US Department of Agriculture
- US Fish and Wildlife Service
- National Park Service
- US Geological Survey
- MA Department of Environmental Protection
- MA Areas of Critical Environmental Concern Program
- MA Department of Agricultural Resources
- MA Natural Heritage and Endangered Species Program
- MA Office of Travel and Tourism
- Massport
- Regional planning agencies (e.g., the Cape Cod Commission, Merrimack Valley Planning Commission)
- Land holders within the MA Bays area (e.g., The Trustees of Reservations),
- Municipalities
- Chambers of Commerce (e.g., Cape Cod Canal Region Chamber of Commerce, Sandwich Chamber of Commerce)
- Counties (e.g., Barnstable County Coastal Resources Committee)
- Cape Cod Cooperative Extension
- MA Marine Biological Lab
- Woods Hole Sea Grant
- Massachusetts universities

- Gulf of Maine Council on the Marine Environment
- Massachusetts Audubon Society
- Wildlife Conservation Society
- Gulf River Association
- Watershed Associations (e.g., Neponset River Watershed Association, Charles River Watershed Association, Mystic River Watershed Association)
- Fisheries and Oceans Canada
- Maine Coastal Program
- Southeastern Massachusetts Aquaculture Center
- Union of Concerned Scientists
- Manomet Center for Conservation Sciences

Potential new funders: These groups were identified as having funded projects relevant to the MBP program, and might have funding opportunities available in the future. Topic areas of interest to each funding source (based on this review of documents) are noted.

Source	Water Quality	Habitat Protection	Continuity of Habitat	Invasive Species	Climate Change
NOAA	X	X	X	X	X
US Fish and Wildlife Service	X	X	X	X	X
National Park Service	X	X	X	X	X
US Geological Survey	X	X	X		X
MA Department of Environmental Protection	X	X	X		X
MA Environmental Trust	X	X	X	X	X
Massport		X			X
Municipalities	X	X	X	X	X
Fisheries and Oceans Canada	X	X	X		X
GE Foundation			X		X
Wildlife Conservation Society					X
The Boston Foundation	X				
Cabot Family Charitable Trust	X				X
Duke Energy		X			